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Abstract

Machine simulation of human reading has caught the attention of computer science researchers since the introduction of digital computers. Character recognition, a branch of pattern recognition and computer vision, is the process of recognizing either printed or handwritten text from document images and converting it into machine-readable form. Character recognition has been successfully implemented for various foreign language scripts like English, Chinese and Latin. In the case of Indian language scripts, the character recognition process is comparatively difficult due to the complex nature of scripts. MODI Script, an ancient Indian script, is the shorthand form of the Devanagari script in which Marathi is written. Though at present, the script is not used officially, it has historical importance. MODI character recognition is a very complex task due to its variations in the writing style of individuals, shape similarity of characters and the absence of word stopping symbol in documents. The advances in various machine learning techniques have greatly contributed to the success of optical character recognition. The proposed work is aimed to explore various machine learning techniques/ methods which can be effectively used in recognizing MODI Script and build a reliable and robust character recognition Model for Handwritten MODI Script.

Keywords :- MODI script, Handwritten Character Recognition, Pattern Recognition, CNN Autoencoder, BiLSTM, CRNN, MODI-Marathi Transliteration, Wavelet Transform.

TABLE OF CONTENTS

Sr. No.	SECTION TITLES	PAGE No.
	ABSTRACT	
1.	INTRODUCTION	1
2.	LITERATURE REVIEW AND RESEARCH CHALLENGES	4
3.	PROBLEM STATEMENT AND OBJECTIVES	9
4.	METHODOLOGY	10
5.	EXPERIMENT AND EVALUATION	19
6.	CONCLUSION AND FUTURE WORK	31
	REFERENCES	32
	LIST OF PUBLICATIONS (JOURNALS AND CONFERENCES)	37

TABLE OF FIGURES

FIGURE NUMBER	FIGURE TITLE	PAGE NUMBER
1	Various Stages of Character Recognition	10
2	The Process Flow of MODI to Marathi Transliteration	12
3	MODI Character Recognition Framework	13
4	Discrete Wavelet Transform	14
5	The Basic CRNN Architecture	18
6	Basic Character Set of MODI Script	19
7	Samples of the Various Styles of MODI Script Documents	20
8	Sample of Handwritten Data of Single Character of MODI Script	21
9	Sample Data Set for MODI /Marathi Transliteration	22
10	An Overview of CNN Model	24
11	The Architecture of Proposed CNN	24
12	The Methodology of CNN Autoencoder based Method	26
13	Basic Encoder-Decoder Architecture	27
14	Process Flow MODI to Marathi Transliteration Model	29

1. INTRODUCTION

In recent years a lot of work has been done towards the digitization of physical documents as it facilitates better searches, modification and quicker addition. This brings a need for software that automates the process of extracting, analyzing, recognizing and storing the information from physical documents. Automatic recognition of either printed or handwritten text from document images and the conversion of it into machine-readable form is called as Optical Character Recognition (OCR) [1]. Over the years, a lot of researchers have worked in this area and have contributed in developing efficient character recognition for various languages. Indian language scripts are generally complex in nature, and hence recognition system for Indian scripts is comparatively difficult. Though technical challenges and lack of commercial market makes it difficult for OCR related research for Indian language, it is the need of the hour [2]. The character recognition process can be categorized into offline character recognition and online character recognition. In the case of the online method, the recognition process is done at the time of writing the character. In offline methods, the recognition is done on the scanned image of the character [3]. The proposed work focuses on offline character recognition.

MODI Script was developed in Devagiri in the 12th century. Hemadri Pandit also known as Hemadpant, a famous leader of the Yadav dynasty, introduced MODI Script. He was inspired by the cursive Sinhalese script and was instrumental in developing a similar one for Marathi which involves less lifting of hand while writing and could be written very fast [4]. MODI was easy to write and was commonly used for writing Marathi until 1950. The usage of the script was reduced when printing technology was introduced in India as it was very difficult for type-setting the script. Because of the difficulty in printing MODI Script, its usage was stopped and Devanagari was used for writing Marathi. In addition to Marathi, there are other languages like Urdu, Kannada, Gujarati, Rajasthani, Hindi, and Tamil which used MODI Script for writing [5]. It has been reported that large volumes of MODI documents are preserved in India as well as other Asian and European countries. Bharat Itihas Sanshodhan Mandal in Pune, Tanjavur's Saraswati Mahal, Rajwade Sanshodhan Mandal, Dhule (Maharashtra) etc., are known to have large collections of such documents. Denmark and other countries have also got some collection of MODI documents [6], [7]. Some of these documents are on the verge of degradation due to improper facilities [8]. Digitization of these documents will help to preserve this large repository of knowledge. It is observed that there is a strong effort to revive the MODI Script by publishing articles written

in the script. In addition, several institutions now offer tutorials for learning MODI. Workshops and formal courses conducted by the Maharashtra State Department of Archives and Bharat Itihas Samshodhak Mandal (BISM) in Pune are examples of such courses. In parallel with the revival of the script, the effort to catalogue and manage large volumes of MODI documents stored at various libraries are also taking place.

The Government of India has initiated the work of cataloguing these manuscripts by appointing trained MODI experts for the job [5]. In this context, there is scope for supporting the revival of the MODI Script by rendering it with appropriate technology. There is a great need for more scholars and experts to come up for the rejuvenation of the MODI script, which will help to preserve the script and thus reinvent this cultural and historical heritage. The proposed study is expected to develop an efficient and robust character recognition model for MODI Script. The effort is to improve the accuracy of handwritten character recognition of MODI script, as there is a scope for improvement.

1.1 Need for the study

- The bulk of documents and correspondence from before Chhatrapati Shivaji's times are written in MODI Script. Realizing that it is impossible to study Maratha history without knowing MODI Script, researchers & enthusiasts are working towards keeping the script alive [9]. The importance of the MODI Script is also evident from the fact that the Script Encoding Initiative (SEI) of the University of California, Berkely, has initiated and completed a project to encode the script, and is currently supported in Unicode [10], [11]
- Research and development in MODI script is necessary to extract the information on MODI manuscripts, which are stored in various parts of India and abroad. Though handwritten character recognition has been successfully implemented for various foreign language scripts, most of the Indian language scripts still need attention. The development of OCR for such script is difficult due to the complex nature of the scripts [12]. Due to MODI being an ancient script and not in the list of scheduled official scripts of Indian languages, very limited work has been done towards the handwritten character recognition of MODI Script compared to other Indian scripts. Intensive research is required towards the development of OCR for historical scripts like MODI, as the script is cursive and complex in nature.
- Research in this field indicates that MODI character recognition needs a different approach/method compared to other Indian script character recognition. Pattern

recognition of MODI script is tedious because of various factors like the shape similarity of characters & inconsistency in writing style [13]. Unlike other scripts, MODI script document does not have any termination symbol for words or sentences, and therefore word segmentation techniques cannot be applied to MODI manuscripts.

- There is a need for more effort to unveil the historical information written in various MODI manuscripts, and therefore the development of an efficient MODI Script recognition model is the need of the hour. Implementation of more efficient methods at the various stages of the character recognition process will increase the performance of character recognition of MODI Script.
- In most of the work which is done on MODI Script character recognition, the data set is specially generated in a controlled environment. The documents which are available in various libraries are ornamental MODI Script and recognition of those is a difficult process, so there is a scope for character recognition on these ornamental MODI Scripts. The proposed study will serve as a preliminary step for the development of a recognition system for MODI manuscript.

2. LITERATURE REVIEW & CHALLENGES

Until 1950, MODI was used as an official script to write Marathi and there are vast amounts of documents preserved in various libraries and hence there is a need to make this information easily available [6], [14], [15]. The revival of the script will enable us to bring the colorful culture of Maharashtra to today's generation. In the year 2013, the Govt. of Maharashtra allocated 80 Lakhs for the digitization of MODI manuscripts. The reports state that there is a serious effort to keep MODI scripts alive [16], [17]. Aimed at preserving and propagating MODI Script, CDAC (Centre for Development of Advanced Computing), Mumbai has done a considerable amount of work on MODI Script and have developed a MODI script software. C-DAC made a website enabling users to convert text from the Devanagari script to MODI and vice-a-versa [18]. In a project funded by the Government of India, Tamil University has taken steps to digitize and catalogue MODI documents by converting it into a Portable Document Format (PDF) [17]. In addition to that, individual researchers have carried out research in MODI script character recognition using various methodologies.

Research in the field of character recognition indicates that the recognition accuracy depends heavily on the feature extraction methods and classification methods used in the recognition process. A study carried out on reviewing the various feature extraction techniques concluded that feature extraction methods of MODI character recognition are still in the infancy stage compared to other Indian languages. The study states that segmentation is the most concerned part in the case of MODI manuscripts, especially as there are overlapping characters and lines in ancient MODI documents [19]. The efficiency of the Zernike feature extraction method was tested for MODI Script character recognition by various researchers [20]–[23]. The observations made by them indicate that the use of Zernike Complex moments features with zoning increases the performance. The similar method was used for Oriya alphabets [24], Devanagari (Marathi) Compound Character Recognition [25], and Arabic characters [26] showed good performance. The performance of Chain Code histogram and Insertion junction feature extraction methods was tested on MODI as well as Devanagari script [27]. Chain Code Histogram based feature extraction method was used for handwritten Bangla characters [28] and resulted in acceptable recognition performance. The classification methods used in their study are KNN, BPN, and SVM. The chain code with SVM fetched the maximum accuracy of 87.5% on Devanagari script & 65% on MODI Script. A structural similarity approach used for the recognition of MODI Script yielded a performance rate of 91 to 97%

[29]. A hybrid approach for feature extraction which combines two techniques: Moment Invariant and Affine Moment Invariant [13], is reported to have achieved an average recognition rate of 89.72%. They claim that the hybrid technique also resulted in extracting minimum features. A similar approach is used for Farsi Character Recognition System [30]. Their research achieved an accuracy of 96.5%. Feature extraction using AMIs (Affine Moments Invariants) technique [31] has been used for MODI character recognition in order to increase the recognition accuracy and reliability.

An analysis of different classification methodologies use in OCR of various languages is carried out, [32] in which the author discusses various classification algorithms used for pattern recognition. The author discussed methods such as Support Vector Machine, Artificial Neural Network, K Nearest Neighbor, Bayesian classifier, and Decision Tree. He also discussed the use of Linear discriminant analysis (LDA), Quadratic Discriminant Analysis (QDA), and Maximum entropy classifier for pattern classification. An insight into different learning based is discussed in [33]. The use of KNN and Backpropagation Neural Network (BPNN) [29] for classification of MODI characters, in combination with structural similarity based feature extraction, has resulted in 91% to 97% recognition rate. Otsu's Binarization algorithm and Kohonen Neural Network based classification method are used for MODI Script Character Recognizer [34] in which various collected datasets were tested and an overall character recognition rate of 72.6%. A recognition model based on image centroid and Chain Code was experimented for vowels in MODI Script [35]. In the classification phase, a two-layer feed-forward Neural Network and SVM was used, and a recognition rate of 65.3% to 73.5% was reported. A theoretical analysis of MODI Script character recognition gives an insight into the basic features of the ancient script [36]. A comparison of the character recognition process of MODI, Devanagari, and Roman scripts was performed in this work and found that in the case of MODI Script structural features were difficult to extract. MODI character recognition and an attempt to convert it into a corresponding English character was carried out [37]. This study lists out different steps of the image processing which can be used for MODI Script character recognition.

A combination of Wavelet energy feature (WEF) and Extreme Learning Machine (ELM) is used effectively and yielded high recognition accuracy in handwritten recognition of Malayalam scripts [38]. The wavelet energy (WE) which is derived using wavelet transform is a new and robust parameter. Character recognition of Marathi compound characters is implemented using wavelet approximation features and modified wavelet features and neural network classifier [39]. In this study, it is observed that recognition accuracy is increased due

to the modified wavelet feature extraction method. Deep learning which was first presented by Geoffrey Hinton et al. [40], [41] is gaining popularity in the recent years for various pattern recognition tasks and is efficiently implemented by various researchers [42]–[44]. Matric learning based Recognition Algorithm called Genetic Programming Matric Learning (GPML) is successfully implemented for Persian/Arabic character recognition [45]. It is learned that this algorithm was efficient in extracting the differentiating geometric shape of the characters and thus produce a minimum set of features. The GP algorithm [46] is widely used in signal processing and pattern recognition.

Convolutional Neural Network (CNN) is implemented by various as it is one of best performing character recognition [43], [44] algorithms. Convolutional Neural Network (CNN) is effectively used for handwritten characters (MNIST Dataset) [47] and for Multi-script Numeral Dataset [28], [48] which yielded a high level of accuracy and is in the upfront of best-performing character recognition algorithms. A framework using Recurrent Neural Network, for the recognition and drawing of handwritten Chinese characters is reported to have achieved a new state-of-the-art performance. It is used for online character recognition as it can directly deal with the raw sequential data, unlike the CNN based method where some image-like representations are required [49]. RNN classifier is also used effectively for offline character recognition of Arabic and Latin scripts [50]. A weighted vote combination of recurrent neural network (RNN) classifiers, each trained with a particular feature set was used in the experiment. The deep Convolutional Neural network is implemented for the character recognition of Hangul Script [51] and to improve upon the performance of the networks. Deep Neural networks (DNN) have been effectively used in pattern recognition tasks. The multiple layers in this kind of networks can efficiently handle more complicated functions than shallow ones [52].

Deep Learning methods are gaining popularity for various pattern recognition tasks [48], [68] in the recent years. They are effectively used for feature extraction as they are able to compress data into smaller dimensions without much loss of information. The field of character recognition also makes use of Deep learning based feature extraction techniques [53]. Anupriya et al., implemented a discriminative autoencoder framework for the feature extraction process of character recognition (of MNIST data set). Using the basic discriminating autoencoder as a unit, they built a stacked architecture to extract relevant representation from the data set.[54]. Stacked Autoencoder (SAE) was also experimented by Mohamed et al., for Arabic handwritten digits recognition. RBM (Restricted Boltzmann

Machine) based feature extraction method was effectively used in recognition of handwritten multilingual numeral data set [55].

Segmentation is one of the most difficult steps in the case of any unstructured documents. The review of literature reveals that very limited work is done on the segmentation of MODI documents. Otsu's binarization algorithm is implemented for the segmentation of MODI Script documents in [34]. A novel approach of text line segmentation, called BATLS (Basic Text Line Segmentation) is implemented for the segmentation of MODI Script documents, and achieved an accuracy of 91% and 94% in the segmentation of overlapping lines and touching lines, respectively [56]. A combination of background and foreground analysis is used for the segmentation of single or multiple touching handwritten numerals [57] and the accuracy reported is 96%. An algorithm using top profile projections is efficiently implemented to segment touching characters in the upper zone of printed Gurmukhi script [46] and has achieved a recognition rate of 91%. A fuzzy multifactorial analysis was used for the segmentation of touching printed characters of Bangala and Devanagari [58]. A Pixel Plot and Trace and Re-plot and Re-trace (PPTRPRT) technique is used for segmentation of Devanagari handwritten scripts for extracting text regions [59]. Performance analysis of character segmentation approach for cursive script recognition is carried out in which the geometric features of the character are analyzed for the segmentation [60]. Reviews of various image segmentation techniques was carried by various researchers in which the recent segmentation techniques used for character recognition are explained [61], [62].

2.1 Research Gap

- Deep Learning based methods have not been experimented on MODI Script by the earlier researchers.
- In most of the work which is done on MODI Script character recognition, the data set is specially generated in a controlled environment but the documents which are available in various libraries are ornamental MODI Scripts.
- Our research aims at implementing Deep Learning Based models as well as the hybrid approach. In addition to specially prepared data we will be using ornamental script as well.

2.2 Challenges

Character recognition of MODI Script is a difficult task due to the fact that characters in MODI are cursive, continuous, unconstrained and also due to the existence of highly similar shaped characters. Segmentation is another challenging task of MODI character recognition process.

- No standard data set available. MODI script is not available on any of the public repositories.
- Data collection of MODI Marathi transliterated documents and data preparation is a time consuming and tedious task. Recognition of ornamental script is a difficult process (ancient script and very limited MODI experts).

3. PROBLEM IDENTIFICATION & STATEMENT

3.1 Problem Statement

Character recognition of MODI Script is a difficult task due to the fact that characters in MODI are cursive, continuous, unconstrained, and the existence of highly similar shaped characters. Segmentation is another challenging task of the MODI character recognition process. Major challenges are caused due to noise and degradation, the presence of multiple skews, fluctuation in illumination, uneven alignment, slanting lines, overlapping lines and touching lines. Thus the focus of the study is to design and develop an efficient Character Recognition Model for Handwritten MODI script by improving upon the recognition accuracy of the present OCR system using soft computing techniques and various emerging learning techniques, and also by implementing the suitable segmentation techniques.

3.2 Objectives

3.2.1 Primary Objective

To design and develop a model for character recognition of MODI Script by improving the recognition accuracy, using soft computing techniques and various emerging learning techniques.

3.2.2 Secondary Objectives:

1. To develop a database for Handwritten MODI characters.
2. To identify and implement a suitable method for text line as well as character segmentation from handwritten MODI documents.
3. To select the best-suited feature extraction and classification techniques for MODI Script and devise an improved method.

4. METHODOLOGY

The proposed model of MODI character recognition and transliteration is performed using independent experimental models.

- The first set of experiments (3 models) is for improving the accuracy of MODI character recognition using Hybrid method as well as Deep Neural Networks. The data set used is isolated characters of the MODI script.
- The next model is for MODI to Marathi Transliteration using Convolutional Recurrent Neural Network (CRNN) based method. The data set used in this model is MODI handwritten documents (lines) and its Marathi transliteration.

The first set of experiments which includes 3 different models are for the character recognition of isolated characters in MODI. The major steps involved in our character recognition system are: Pre-processing, Segmentation, Feature Extraction and Classification. The process flow diagram for our character recognition model is shown in Fig.1.

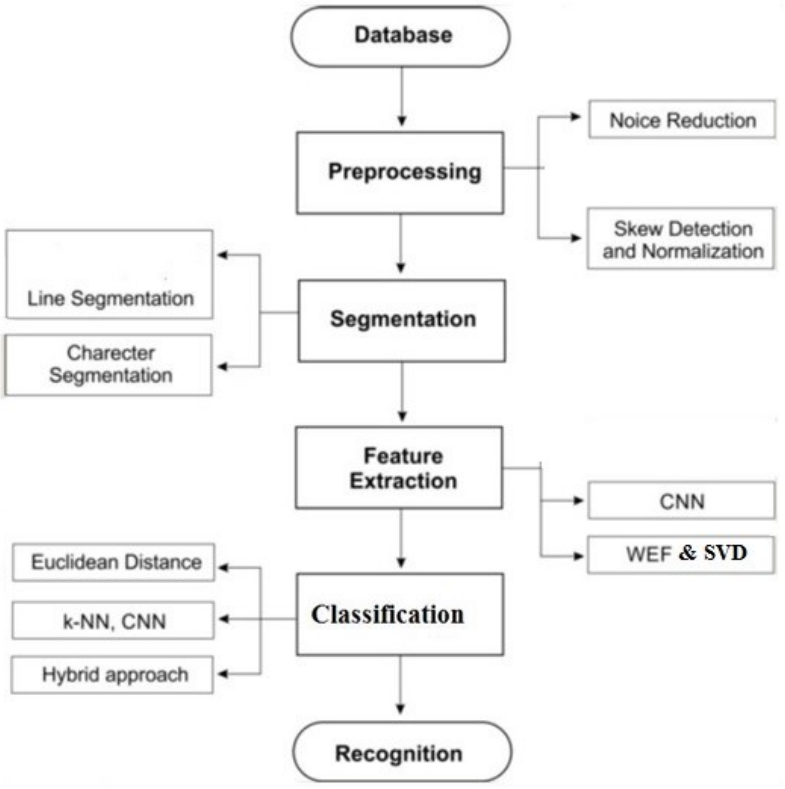


Fig.1: Various Stages of Character Recognition

Pre-processing is used to eliminate the noise of the document. There are various pre-processing techniques such as Noise Reduction, Skew Detection and Normalization which can be used at this stage [66].

In the segmentation step, the document is subdivided into components like words, lines, and characters. The accuracy at this stage affects the accuracy of the entire process. The segmentation of connected handwritten character is a main bottleneck in the OCR system [50], [52].

The extraction of the most representative information from the raw data is called feature extraction. A feature point is the distinguishing feature of the character image, and such features will be recognized at this stage with a fixed number of feature variables [34]. The extracted features of each class are used for distinguishing it from the other classes. There are various feature extraction methods available for the selection of important features. Identifying the suitable feature extraction method is essential for achieving an excellent recognition performance. We have used deep learning based methods (CNN autoencoder) as well as hybrid method (WT-SVD) for feature extraction.

The classification stage is instrumental in mapping an unknown sample into a predefined class. The quality of the extracted features determines the performance of the classifier. Various methodologies of pattern recognition are used at this stage for classification purpose. Support Vector Machine, K-Nearest Neighbour and Euclidean Distance classifier are the methods used in our experimental models.

The proposed design for the transliteration of handwritten MODI manuscript to Marathi text is shown in Fig. 2.

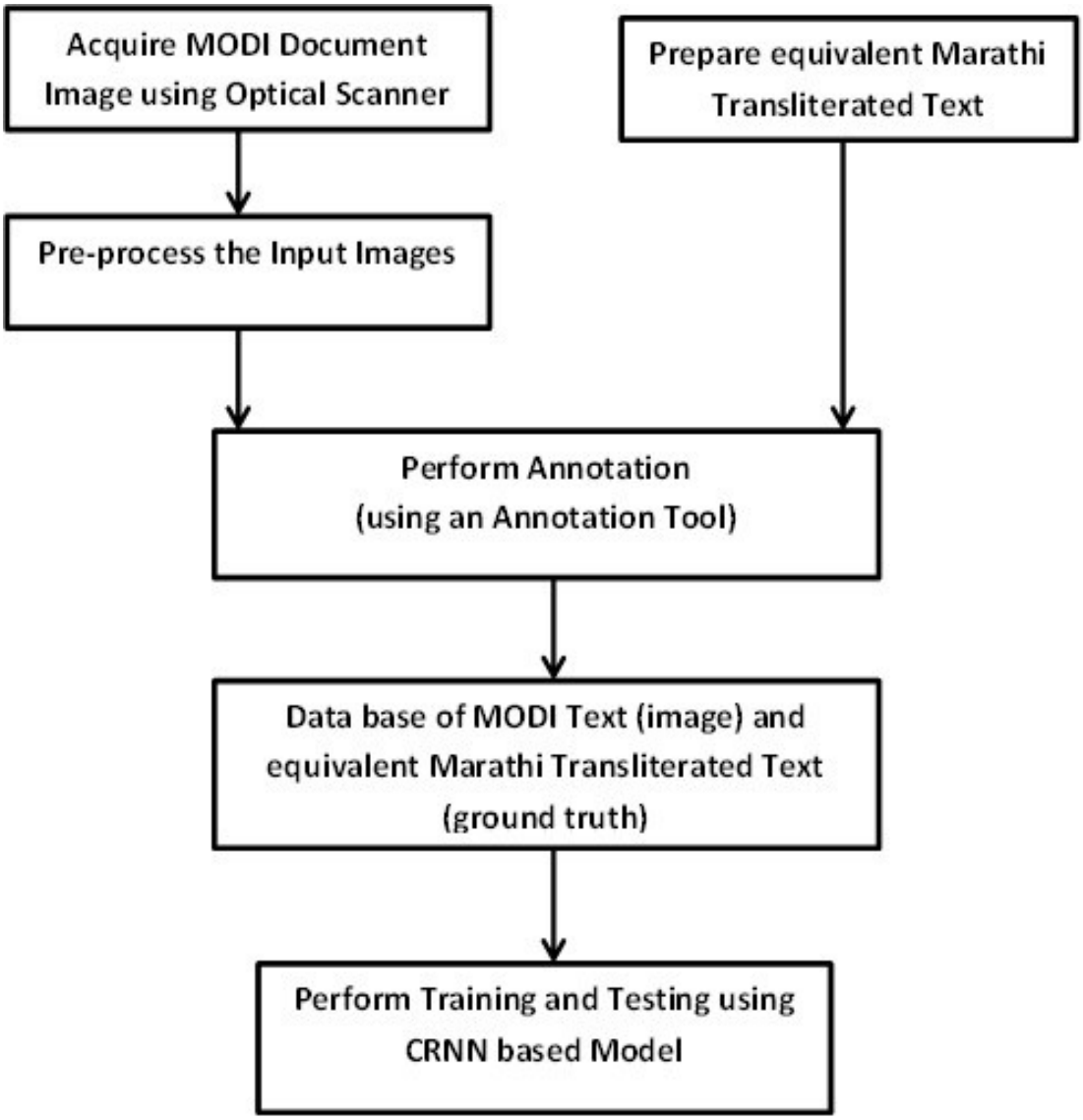

Acquire MODI Document Image using Optical Scanner
Prepare equivalent Marathi Transliterated Text
Pre-process the Input Images
Perform Annotation (using an Annotation Tool)
Data base of MODI Text (image) and equivalent Marathi Transliterated Text (ground truth)
Perform Training and Testing using CRNN based Model

Fig. 2: The Process Flow of MODI to Marathi Transliteration

The implementation of the model is performed using the following steps:-

- Training/testing data set is prepared by scanning the document (300 dpi) and performing the line segmentation
- Annotation is performed using an annotation tool (for each MODI script line image, the Marathi equivalent is to be entered).
- Use a Deep Learning based method for character recognition (CRNN - Convolutional Recurrent Neural Network based Calamari OCR is used as the base model)

4.1 Model Description

The various models used in the above mentioned character recognition as well as the transliteration is depicted in Fig. 3

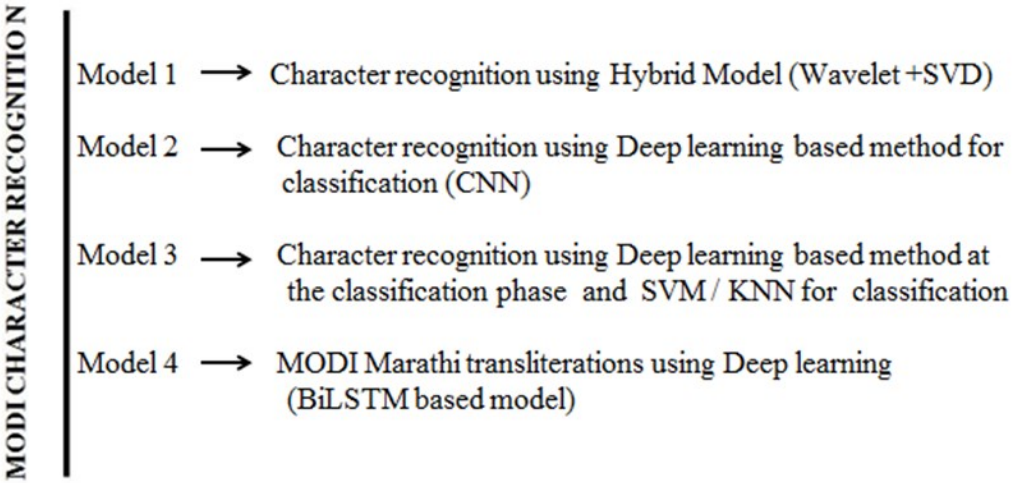

MODI CHARACTER RECOGNITION
Model 1 → Character recognition using Hybrid Model (Wavelet +SVD)
Model 2 → Character recognition using Deep learning based method for classification (CNN)
Model 3 → Character recognition using Deep learning based method at the classification phase and SVM / KNN for classification
Model 4 → MODI Marathi transliterations using Deep learning (BiLSTM based model)

Fig. 3: MODI Character Recognition Framework

The implementation is done using four experimental models. A brief description of the four models mentioned above is given in the following section. The detailed description of the model and the experimental results of each of the models are given in section 5.3.

4.1.1 Character Recognition using Wavelet & SVD

The focus of this model is feature extraction. We have designed a hybrid model called WT-SVD for feature extraction of the MODI script by combining Wavelet Transform (WT) and Singular Value Decomposition (SVD) techniques.

4.1.2 Character Recognition using Convolutional Neural Network

This model uses CNN, along with on-the-fly Data Augmentation, to classify and recognize the characters of the ancient MODI Script. The augmentation of the data will add variability and generalization to the dataset, which will result in better accuracy while training the network.

4.1.3 Character Recognition using CNN Autoencoder based Feature Extraction and SVM /KNN for Classification

A CNN autoencoder based feature extraction method is used in this model. The classification is performed using Support Vector Machine (SVM) and also using K Nearest Neighbor (KNN)

4.1.4 Character Recognition using Convolutional Recurrent Neural Network (CRNN) for MODI to Marathi Transliteration

This model used Recurrent Neural Network based on Calamari OCR for the transliteration of MODI script lines images to Marathi text.

4.2 Methods used for Feature Extraction

4.2.1 CNN Autoencoder

An autoencoder is a type of artificial neural network used to learn efficient data codings in an unsupervised manner. The aim of an autoencoder is to learn a representation (encoding) for a set of data. Autoencoders can be great for feature extraction as they can be trained to learn a fixed dimensional latent space representation of a given image. An autoencoder is generally composed of two blocks, such as an encoder and a decoder. The encoder part is used to transform the input data into a low dimensional representation. Using the transformed low dimensional representation, the decoder part of the autoencoder regenerates the input. In the encoder, the input image is compressed with max-pooling followed by convolutions. In the decoder, the compressed input image is decompressed with up-sampling [53][69]. This way, the autoencoder is able to identify useful features of the input data without the requirement of any labels. The implementation of the autoencoder can be performed using various types of neural networks, e.g., Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), etc. [70].

4.2.2 Wavelet Transform

Wavelet functions defined around a certain point are concentrated both in time and frequency. It is a well-suited function in the time-frequency domain analysis for a non-stationary signal. Wavelet Transform can be used to separate the input signal into details (horizontal, vertical and diagonal) and approximate sub-signals as shown in Fig 4. Given ‘n’ decomposition wavelet coefficients from the three sub-signals are used for formulating wavelet energy [71].

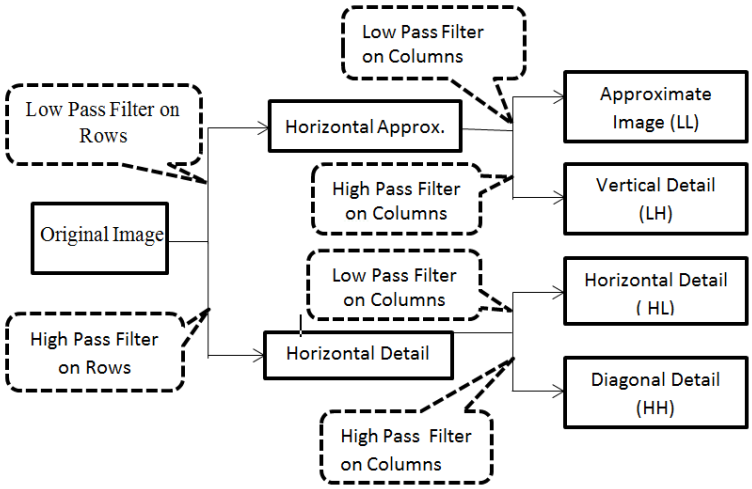


Fig. 4: Discrete Wavelet Transform

The wavelet energy of horizontal, $e_n^H(x,y)$, vertical $e_n^V(x,y)$ and diagonal $e_n^D(x,y)$ detail sub-signals, at the pixel position (x,y) at each of the level are as follows

$$e_n^H(x,y) = \sum_{r,s\in Z} (D_H)^2 G(x-r, y-s)$$

$$e_n^V(x,y) = \sum_{r,s\in Z} (D_V)^2 G(x-r, y-s) \quad (1)$$

$$e_n^D(x,y) = \sum_{r,s\in Z} (D_D)^2 G(x-r, y-s)$$

where D_H, D_V and D_D are the wavelet coefficients at the pixel position (x,y) of the horizontal, vertical and diagonal detail sub-signals, respectively. Z refers to the set of integers. r and s are the x-coordinate and y co-ordinate of the neighbourhood pixel, respectively. $G(x,y)$ is the two-dimensional Gaussian kernel function given by:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{\left(\frac{-(x^2+y^2)}{2\sigma^2}\right)}$$ where σ is the standard deviation of the kernel. (2)

4.2.3 Singular Value Decomposition (SVD)

Singular Value Decomposition is a factorization of a matrix to a matrix of lower dimensions. It states that a real matrix 'A' of size m x n can be decomposed into a product of 3 matrices U, ∑ and V such that:-

A mxm = U mxn ∑ mxn V mxn T (3)

Where U and V are orthogonal matrices and ∑ is a diagonal matrix of dimension same as matrix A. SVD is a powerful technique for dimensionality reduction and has a number of applications.

4.3 Methods used for Classification

4.3.1 Convolutional Neural Network (CNN)

Convolution Neural Network is a special kind of deep learning technique, which consists of input and output layers with many hidden layers between them. It uses the convolution concept of linear operation from mathematics. The hidden layers include the convolution layer, the pooling layer and the fully connected layer [72].

The convolutional layer is the layer that does the feature extraction of the sharp features of the input images such as corners, edges and endpoints. It will help in reducing the size of the images. A set of convolution kernels constitute the convolution layer [3]. The feature mapping function is given as follows:

$$Fi+1 = \alpha(Fi*K+b) \quad (4)$$

Where α is the activation function, b the bias, * is the convolutional operation.

The neural network uses various activation functions to determine its output. The widely used activation functions are sigmoid, Tanh, Rectified Linear Unit (ReLU), Softmax, etc. ReLU is generally used in order to add non-linearity to the convolution layers. It converts all the negative values to zero. The function is given by

$$ReLU(Fi)=max(Fi,0) \quad (5)$$

The output image is then passed on to the pooling layer, which is used to reduce the spatial volume of the input images. This layer comes between the convolutional layers. Average and max-pooling are the most commonly used pooling layers.

The fully connected layer connects neurons in one layer to neurons in another layer. It is used for image classification by training the images. The visual features after the convolution and pooling layer are transferred to fully connected layers and the function is given by,

$$Fi+1== \alpha(Fi.W+b), \quad (6)$$

where '.' represents the matrix multiplication, α is the activation function, b the bias and W the weight matrix.

The last fully-connected layer consists of m neurons, where m is the number of predicted classes [73].

4.3.2 Support Vector Machine (SVM)

The classification of extracted features is performed using the Support Vector Machine. An SVM classifier is a supervised machine learning model that can be effectively used for classification and regression. It is more commonly used for classification problems in machine learning as they perform better compared to some of the other classifiers. They can be effectively used even when the data set is small. It is also observed that SVM is better in generating good classifiers and also good in generalizing [74]. This algorithm outputs the optimal hyper-plane and maximizes the margin between two classes. SVM has a kernel trick to obtain better accuracy. Linear Kernel, Polynomial Kernel, Gaussian Kernel, Radial Basis Function (RBF), etc. are the commonly used kernels in SVM [75]. In our experiment RBF kernel is used, which is expressed as:-

$$K(x,x') = \exp\left(-\frac{\| x - x' \|^2}{2\sigma^2}\right) \tag{7}$$

where $\| x_i - x_j \|^2$ is recognized as square Euclidean distance between the two vectors and σ is a kernel parameter.

4.3.3 Decision Tree

The extracted features are then subjected to classification using the Decision Tree classifier. A Decision Tree classifier is a supervised machine learning model that can be effectively used for classification and prediction. It is a flowchart like a tree structure, where each internal node denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (terminal node) holds a class label. The classification is performed by recursively partitioning the source set into subsets based on an attribute value.

4.3.4 Euclidean Distance

After the feature extraction stage, the Euclidean classifier is used for classification for matching the test data samples against the train samples. The distance between the two templates is calculated to produce the similarity score. This distance is calculated by the equation shown below

$$\text{Distance} = \sqrt{(T_1 - T_2)^2}\ , \tag{8}$$

where T_1 and T_2 are templates to be matched.

4.3.5 K-Nearest Neighbors (KNN)

K-Nearest Neighbors (KNN) algorithm is a type of supervised ML algorithm which can be used for both classification as well as regression predictive problems. However, it is mainly used for classification. It is a simple algorithm that stores all available cases and classifies new cases based on a similarity measure (e.g., distance functions). KNN helps us find which class the new input (test value) belongs to when k-nearest neighbours are chosen and distance is calculated between them.

4.4 CRNN based Calamari OCR for Transliteration

Calamari is an open-source OCR recognition software that uses the most advanced deep neural network, implemented by Tensorflow. The customizable network architecture composed of Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) layers is trained by the Connection Time Classification (CTC) algorithm. The basic architecture of CRNN architecture is shown below in Fig. 5.

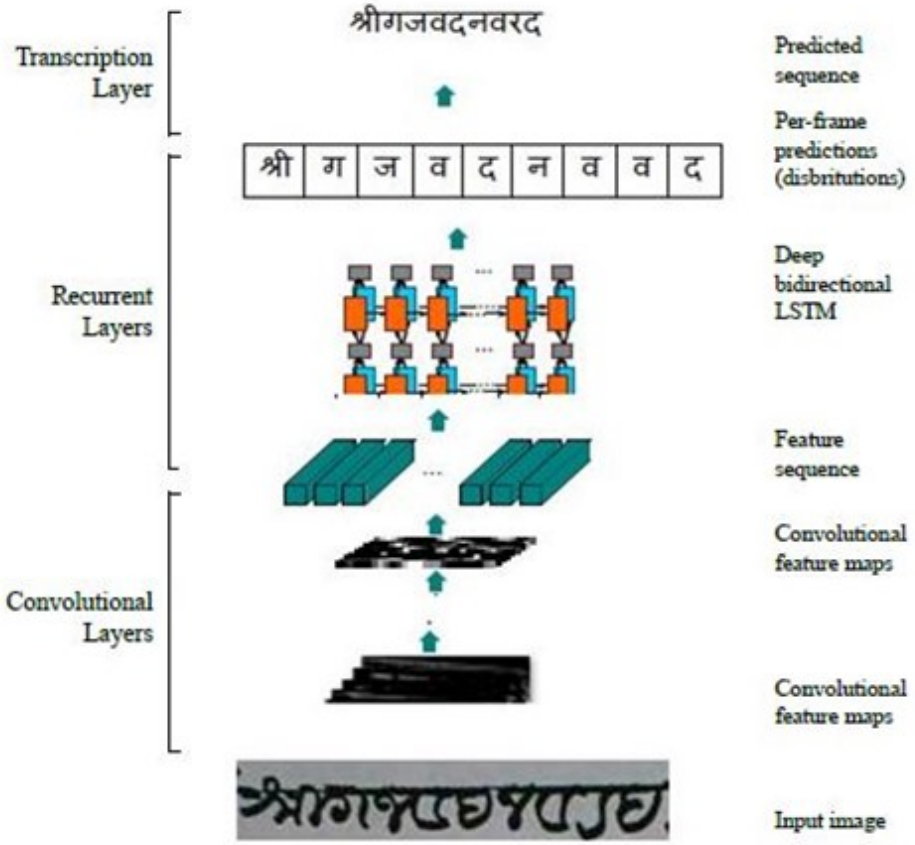


Fig. 5: The Basic CRNN Architecture

The default network of this CRNN model consists of a stack of two CNN and Pooling-Layers, respectively and followed by a LSTM layer.

5. EXPERIMENTS AND RESUTS

5.1 Description of the Dataset

MODI Script is an ancient script which was used in the 12th century for writing Marathi. This script was widely used between the 12th century and 20th century. The name 'MODI' is believed to be derived from the Marathi verb moḍaṇe (Marathi: मोडणे), which means "to bend or break" [5]. The script was written by 'Boru' or 'Lekhan'. 'Lekhan' was a pen created with bamboo. MODI Script is derived from the Nagari family of scripts and intended for continuous writing. Although MODI is based upon Devanagari, there are some significant differences. The differences are evident in letter forms, rendering behaviors, and orthography of both the characters. The behaviors of these characters in certain environments, such as consonant-vowel combinations and conjunct consonants, that are standard features of MODI orthography and is different from Devanagari script. The MODI script has 46 distinctive letters, of which 36 are consonants and 10 vowels (Fig.6). MODI was written as characters hanging on a horizontal line which is drawn across the page. Termination symbol for sentence or word was not used in MODI Script. The speed of writing was increased due to the elimination of these symbols as it avoided the lifting of the "Boru' too often [19].

a ā i u e ai o au aṃ aḥ
ka kha ga gha ṅa ca cha ja jha ña
ṭa ṭha ḍa ḍha ṇa ta tha da dha na
pa pha ba bha ma ya ra la va
sha ssa sa ha lla kha dny

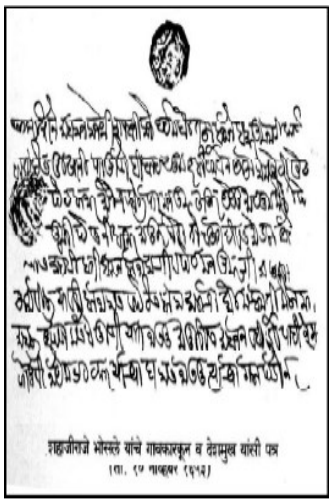
Fig. 6: Basic Character Set of MODI Script

There are several styles of the MODI Script based on the era. The different styles of the script and the time period is shown in table 1.

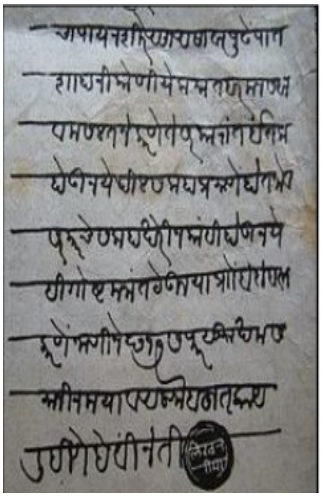
Table 1: Various Styles of MODI Scripts with the Time Period

Sr. No.	Styles of MODI Script	Time Period
1	Adya Kalin (proto-MODI)	12th century
2	Yadav Kalin	13th century
3	Bahamanikalin	14th to 16th century.
4	Sivakalin	17th century.
5	Chitnisi	18th century
6	Peshvekalin	till 1818
7	Anglakalin	1818 to 1952.

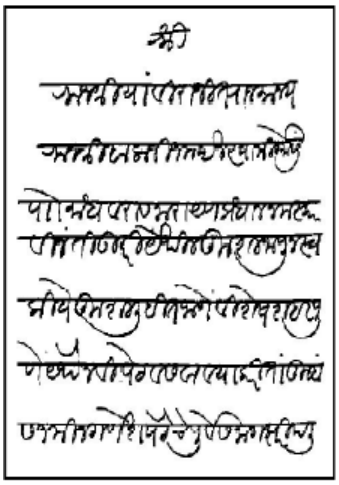
Bahamanikalin, Chitnisi , Peshvekalin and Anglakalin are found to be commonly used in historical manuscripts. In addition, a style of MODI was used in primary school books produced during the 19th and 20th centuries. The major styles are depicted in Fig.7.



Bahamanikalin



Chitnisi



Peshvekalin

Anglakalin School Book Script

Fig.7: Samples of the Various Styles of MODI Script Documents

The data set used in our experiment model includes:-

- Isolated MODI characters
- MODI manuscripts.

5.1.1 Isolated MODI Characters

Handwritten characters written by different people were used in the first 3 experimental models. The initial data set for the experiment consists of 4600 MODI characters, of which 3220 are used as train samples and 1380 as test samples (70:30 ratio). A sample data sheet is shown in Fig.8.

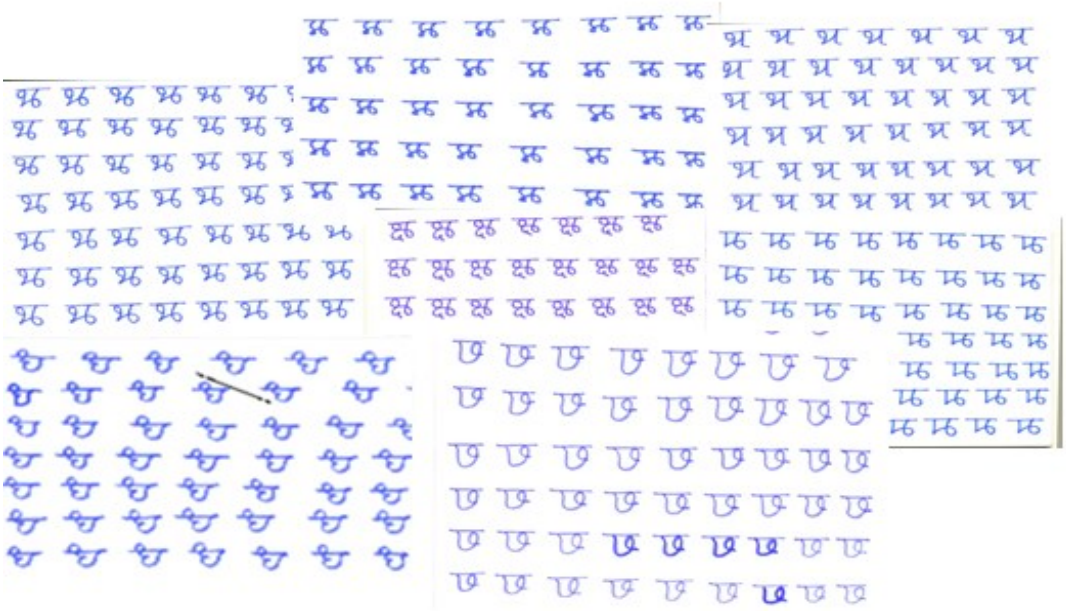


Fig. 8: Sample of Handwritten Data of Single Character of MODI Script

5.1.2 Dataset of MODI Handwritten Manuscripts for Transliteration

The handwritten manuscripts for MODI-Marathi transliteration (Fig.9) was collected from the various libraries listed below:-

- Bharat Itihas Sanshodhak Mandal, Pune
- Maratha History Museum (Deccan College, Pune)
- The Bhandarkar Oriental Research Institute, Pune
- Directorate Of Archives and Archaeology, Goa
- Xavier Institute of Historical Research, Goa

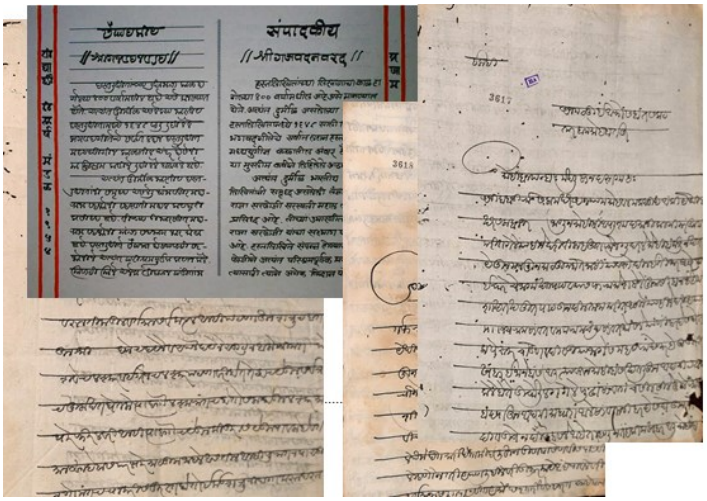


Fig. 9: Sample Data Set for MODI /Marathi Transliteration

5.2 Tools Used

The implementations will be carried out using the Python environment with Tensorflow and Keras.

Keras is an Open Source Neural Network library written in Python that runs on top of Theano or Tensorflow. Keras is very quick to make a network model. Keras High-Level API handles the way we make models, defining layers, or set up multiple input-output models.

5.3 Experimental Results and Performance Analysis

5.3.1 Experimental Model using Hybrid Method (Wavelet & SVD)

In this model, we have focused on the feature extraction stage. We have designed a hybrid model called WT-SVD for the feature extraction of MODI script (isolated characters), by combining Wavelet Transform (WT) and Singular Value Decomposition (SVD) techniques. The extracted feature of the image is then subjected to classification using Euclidean distance. The steps followed in this model are shown in Table 2.

Table 2: The Steps of the Proposed Wavelet & SVD Method

Steps	Description
Step 1	Read the Training Data set.
Step 2	Apply Wavelet Transform on input image for feature extraction (use the approximate sub-signal) as the features.
Step 3	Apply SVD for dimensionality reduction on the resultant approximate image.
Step 4	Repeat the above steps for the Test data set.
Step 5	Perform classification using the Euclidean Distance method

5.3.2 Experimental Model using Augmented CNN for MODI Script Character Recognition

The character recognition of handwritten MODI script using a CNN based method is performed in this model. The augmentation of the data will add variability and generalization to the dataset, which will result in better accuracy while training the network. The steps followed in the implementation are given in Table 3.

Table 3: The Steps followed in the Augmented CNN Method.

Steps	Description
Step 1	Input the original image
Step 2	Apply image augmentation
Step 3	Generate randomly Transformed batch of Images
Step 4	Train the network i) Apply Convolutional filter on the input image with ReLU activation function. ii) Apply Max Pooling for down-sampling. iii) Repeat steps i) & ii) with varying numbers of filter counts and kernel sizes. iv) Apply a fully connected layer (two hidden layers) on the extracted features. v) The output layer is constructed with 46 nodes to get the results for 46 characters.

The original image (60*60 pixels) is given as the input and a data augmentation method will be applied to it. After the data augmentation, the data is passed through the Convolutional Neural Network for the recognition of characters, as shown in Fig 10.

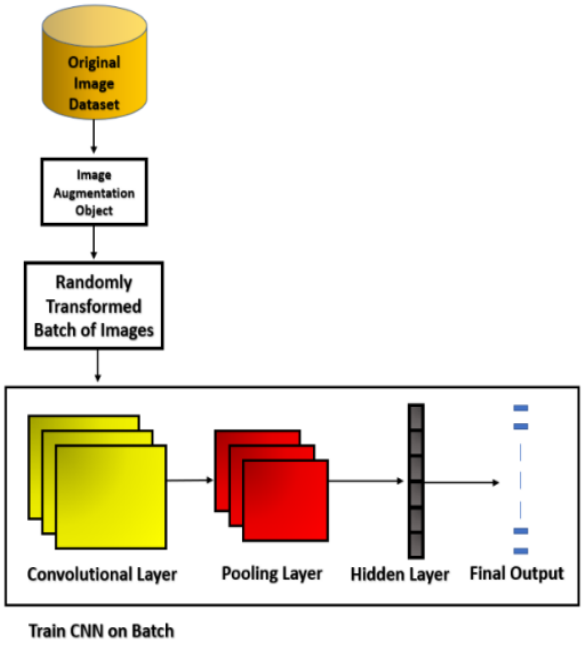


Fig. 10: An Overview of CNN Model

The proposed architecture for handwritten MODI character recognition is shown in Fig. 11. The classification model has ten convolutional layers, five pooling layers (2*2 sub-matrices) and three dense layers (two fully connected layers and one output layer). The convolutional layer is used for feature extraction and by increasing the number of convolutional layers, the accuracy of feature extraction can be improved.

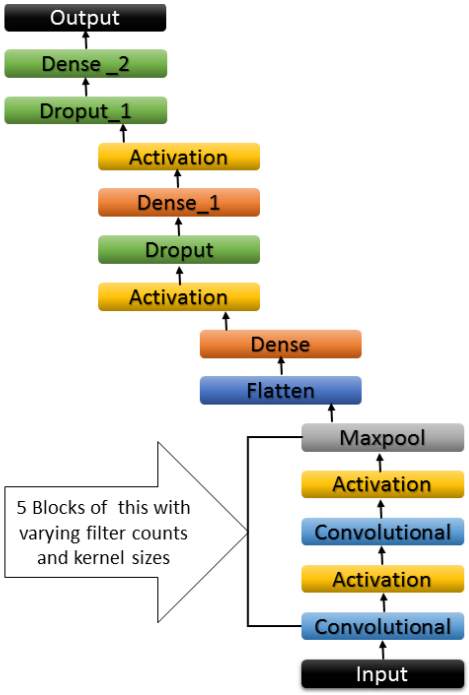


Fig. 11: The Architecture of Proposed CNN

This architecture takes a greyscale image as input (60* 60-pixel size). The on-the-fly data augmentation is performed on the image using ImageDataGenerator (flip, horizontal and vertical, 45^0). The input image is passed through the first convolutional layer (32 filters of window size 2 × 2). The activation function used is ReLU, which is one of the most commonly used functions used in CNN for nonlinearity. Subsequently, a pooling layer is used for down-sampling. The Pooling layer has 2*2 sub matrices (Max pooling is used in this case). As a result, the image volume is reduced and filter samples are increased. The convolution and Max pooling operation is repeated serially with the varying numbers of filter counts (32, 64,128, 256,512). A Flatten layer is added to convert the pooled feature map to a single column that is passed to the fully connected layers. The features are then passed through two dense layers of 256 nodes each. The ReLU activation function is used for the dense layers. Two dropout functions are added between the two hidden layers. Dropout functions are used to prevent over fitting. The output layer is constructed with 46 neurons for the classification of 46 classes in the MODI character set. The sigmoid activation function is used at the output layer.

As the initial data set, 4600 MODI characters are used in the experiment. 3220 are used as train samples and 1380 as test samples (70:30 ratio). Data Augmentation is performed using ImageDataGenerator function (of Keras), which performs on-the-fly data augmentation. ImageDataGenerator does real-time data augmentation.

The accuracy achieved using this model is 99.78%, which is better compared to any other MODI character recognition method reported so far. A comparison of the result with the existing highest accuracy method is given in Table 4.

Table 4: MODI Script Recognition Accuracy using the Proposed Method and a Comparison with the Existing Method.

Sr. No	Author/Method	Feature Extraction & Classification	Data Set	Accuracy
1	The ACNN Method	CNN	MODI character set of 46 characters	99. 78 %
2	Sadanand et al.,	Zernike moments & Euclidean Distance	MODI character set of 46 characters	94.92 %

The CNN architecture of our method is designed with appropriate parameters for good accuracy of the MODI Script character recognition.

5.3.3 Experimental Model using CNN Autoencoder for Feature Extraction and SVM/KNN for Classification

This model uses CNN autoencoder for feature extraction and KNN/SVM for the classification. The step by step procedure of the methodology is shown in Table 5.

Table 5: The Steps of the Proposed CNN Autoencoder based Method.

Steps	Description
Step 1	Input the Image
Step 2	Apply Image Augmentation
Step 3	Generate randomly transformed batch of Images
Step 4	Apply CNN Autoencoder to extract features
Step 5	Use SVM /KNN for the classification of the extracted features.

The original image (60*60 pixel size) is given as the input and data augmentation method will be applied to it. After the data augmentation, the data is passed through the CNN autoencoder for the extraction of features.

The proposed methodology is depicted in Fig. 12.

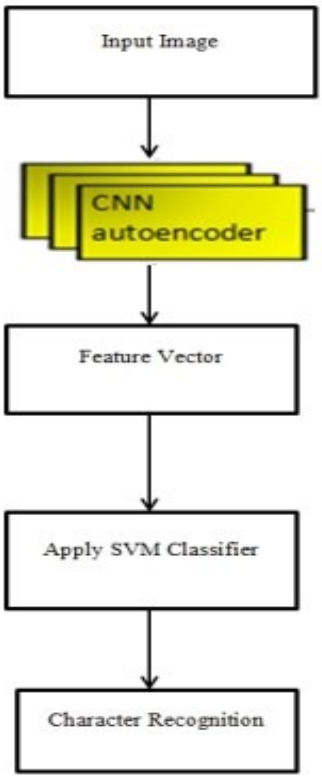


Fig. 12: The Methodology of CNN Autoencoder based Method

In this model, an autoencoder with CNN is implemented for the feature extraction of MODI character recognition. The basic encoder-decoder architecture is shown in Fig. 13. The CNN autoencoder architecture in our model consists of three convolutional layers (of 3*3 kernel size). The activation function used in all the layers is ReLU, which is one of the most commonly used functions in CNN for nonlinearity. Convolutional layers are followed by pooling layer (2 by 2 max-pooling) for down-sampling (as a result, the image volume is reduced and filter samples are increased). A Flatten layer is added to convert the features to a single column. The decoder has a similar architecture (as shown in Fig. 4). All the layers have ReLU activation. Adam optimizer is used for training the deep model. The Loss function used is Mean Squared Error (MSE) loss. The exact architecture of the model used is given in Fig. 13.

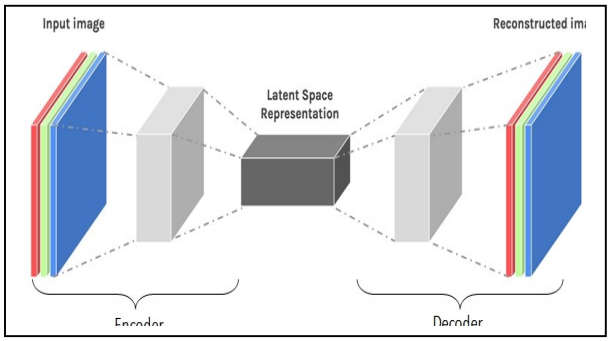


Fig.13: Basic Encoder-Decoder Architecture

The classification of extracted features is performed using the Support Vector Machine as well as K-Nearest Neighbor.

The data set for the experiment consists of 4600 MODI characters, of which 3220 are used as train samples and 1380 as test samples (70:30 ratio). Handwritten characters written by different persons were used for the study. The experiment is conducted using Python programming.

After pre-processing, the grayscale image was size-normalized to fit in a 60x60 pixel box. Data augmentation is performed on the training data set using ImageDataGenerator function (Keras). ImageDataGenerator performs on-the-fly/real-time data augmentation. All the original images are transformed at every epoch and then used for training. This way the learned model tends to become more robust and accurate as it is trained with different variations of the same image. The augmentations used in this experiment are scaling and rotation (300). The randomly generated data is then given as the input for the CNN autoencoder. The output of the encoder is a 300-dimensional vector and thus, 300 features were extracted from the input image (of size 60x60).

The output of this level (the extracted features) is used for the classification. The classification is performed using Support Vector Machine with Radial Basis Function (RBF) kernel. The accuracy achieved is 99.3%. Table 4 shows the accuracy achieved using CNN autoencoder feature extraction method in combination with SVM classifier as well as KNN classifier.

Table 6: Results Comparison with the other Methods of MODI Script OCR in Literature.

Sr. No	Feature Extraction	Classification	Accuracy
1	CNN Autoencoder	SVM	99.3 %
2	CNN Autoencoder	KNN	94.4 %

The accuracy obtained using our method is better compared to any other MODI character recognition work reported so far. It was observed that a similar-looking character gave false predictions, as the system was not able to distinguish some images.

In this work, the implementation of CNN autoencoder as a feature extractor is proposed for the character recognition of the MODI script. The feature set size was reduced from 3600 to 300 with CNN autoencoder. The extracted features were then subjected to classification using SVM. An accuracy of 99.3% is reported, which is better compared to any other reported accuracy of MODI script character recognition.

5.3.4 Experiment Model using Convolutional Recurrent Neural Network (CRNN) for MODI to Marathi Transliteration

This model is used for the transliteration of the MODI script text to Marathi text. Calamari OCR, an open-source software, is used as the base for the proposed model. The default network of this CRNN model consists of a stack of two CNN and Pooling-Layers, respectively and the following LSTM layer and CTC layer.

We have fine-tuned the customizable Calamari OCR to suit the purpose of MODI character recognition. The fine-tuned network in the proposed model consists of 3 CNN & Pooling Layers followed by an LSTM layer.

The customized network model which is used for MODI to Marathi transliteration consists of a stack of three CNN layers with 256, 512 and, 1024 filters, respectively (as described in section 4.3.2). These 3 layers are followed by an LSTM with 200 filters and a dropout rate of 0.5.

The dataset consists of scanned images of MODI script lines of text and its equivalent Marathi text as the ground truth data. The ground truth of each of the images was entered through the annotation tool (The tool's user interface is depicted in figure 5.5).

Images of 4000 words and it’s transliteration in Marathi (in Unicode) was used in the experiment. The data set was divided into 800 for testing and 3200 for training (20:80 ratio). An accuracy of 78.4% was achieved after fine-tuning the network.

6. CONCLUSION AND FUTURE WORK

There is a huge collection of MODI documents preserved in India as well as in other Asian and European countries. Research on these documents can be improved by deciphering MODI script. There is a need to unveil the historical information written in various MODI manuscripts; therefore the development of an efficient MODI Script recognition model is the need of the hour. Research in this field indicates that MODI character recognition needs a different approach/method compared to other Indian script character recognition. The final outcome of our research is an efficient character recognition of the MODI Script using deep learning techniques. The implementation is performed using four models. The first 3 models are for the character recognition of isolated MODI characters and the fourth model is for MODI-Marathi transliteration. The experimental model using CNN resulted in an optimized solution for the character recognition of MODI script by getting a very high accuracy of 99.78 which is higher than the reported accuracy so far. The data set was augmented before training the network. The fourth model is for the MODI to Marathi transliteration and this was the first of its kind in MODI document analysis. MODI to Marathi transliteration was a very challenging task as MODI script documents are complex in nature and also due to the fact that there is no standard data set available for the experiment. The outcome of the research is as follows:-

1. Developed a database of Handwritten MODI text lines and transliterated Marathi lines for training the network.

2. With the use of Deep Learning based and hybrid method, BiLSTM performed MODI script recognition as well as transliteration of it to Marathi. MODI to Marathi transliteration is not yet experimented by any researcher. This research work will contribute considerably in the field of MODI script document analysis.

As a future work, we will be experimenting with other deep learning based models to improvise the accuracy of MODI/ Marathi transliteration. Segmentation is another challenging task in MODI OCR and we will be concentrating on the segmentation of unconstrained MODI script documents as well.

RFERENCES

[1] A. Chaudhuri, K. Mandaviya, P. Badelia, and S. K Ghosh, *Optical Character Recognition Systems for Different Languages with Soft Computing*, vol. 352. 2017.

[2] R. Jayadevan, S. R. Kolhe, P. M. Patil, and U. Pal, "Offline recognition of Devanagari script: A survey," *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.*, vol. 41, no. 6, pp. 782–796, 2011.

[3] T. Capin and K. Pulli, "The State of the Art in online handwriting recognition," *IEEE Trans. Pattern Aalysys Mach. Intell.*, vol. 12, no. August, pp. 787–808, 1990.

[4] R. A. Ramraje, "History of MODI Script in Maharashtra," *Glob. Online Electron. Int. Interdiscip. Res. J. (GOEIIRJ)*, vol. 2, no. 1, 2013.

[5] A. Pandey, "Final Proposal to Encode the MODI Script in ISO / IEC 10646," pp. 26–27, 2011.

[6] R. Thakre, "Reviving MODI Script," *Typography 2014*, 2014. [Online]. Available: http://shivajiscript.blogspot.com/. [Accessed: 05-Dec-2018].

[7] R. Khillari, "History of MODI Script," *Shri Modi Vibhav*, 2008. [Online]. Available: http://modi-script.blogspot.com/2008/05/history-of-modi-script.html.

[8] M. . Y. Savant and K. Rakshana, "Marathi MODI Script: Origin, Evolution and Significance," *A bi-monthly Publ. Natl. Mission Manuscr.*, vol. 1, no. 1, p. 16, 2018.

[9] Times, "Band of researchers, enthusiasts strive to keep MODI script alive," *Times of India*, Pune, 2014.

[10] Linguistics-Department, "Progress Overview," *University of California,Berkeley, Script Encoding Initiative*. .

[11] Berkeley-Linguistics, "Script Encoding Initiative," *Department of Linguistics, University of California*, 2018. [Online]. Available: http://linguistics.berkeley.edu/sei/progress-overview.html. [Accessed: 04-Jun-2018].

[12] J. John, K. V Pramod, and K. Balakrishnan, "Handwritten Character Recognition of South Indian Scripts : A Review," in *Proceedings of National Conference on Indian Language Computing*, 2011, pp. 1–6.

[13] S. S. Gharde and R. J. Ramteke, "Recognition of characters in Indian MODI script," *Proc. - Int. Conf. Glob. Trends Signal Process. Inf. Comput. Commun. ICGTSPICC 2016*, pp. 236–240, 2016.

[14] Wikiquote, "Marathi Language." [Online]. Available: https://en.wikiquote.org/wiki/Marathi_language. [Accessed: 03-May-2017].

[15] P. Deshpande, "Rare Manuscripts to be Digitised by Archives Dept.," *MID DAY INDIA NEWS*, Pune, 2013.

[16] Hindu, "House library panel visits Saraswathi Mahal," *The Hindu*, Tanjavur, 2007.

[17] Hindu, “MODI documents of Maratta era to be digitised,” *The Hindu*, Tanjavur, 2013.

[18] CDAC, “Modi Script Tools,” *Centre for Development of Advanced Computing*, 2016. [Online]. Available: https://www.cdac.in/index.aspx?id=pk_itn_spot1006. [Accessed: 06-Jun-2018].

[19] S. Kulkarni, P. Borde, R. Manza, and P. Yannawar, “Review on Recent Advances in Automatic Handwritten MODI Script Recognition,” *Int. J. Comput. Appl.*, vol. 115, no. 19, pp. 975–8887, 2015.

[20] K. Sadanand, P. L. Borde, M. Ramesh, and Y. Pravin, “Offline MODI Character Recognition Using Complex Moments,” *Procedia Comput. Sci.*, vol. 58, pp. 516–523, 2015.

[21] S. Kulkarni, P. Borde, R. Manza, and P. Yannawar, “Recognition of Handwritten MODI Numerals using Hu and Zernike features,” *CoRR*, vol. abs/1404.1, pp. 1–7, 2014.

[22] K. Sadanand, P. Borde, M. Ramesh, and Y. Pravin, “Impact of zoning on Zernike moments for handwritten MODI character recognition,” *IEEE Int. Conf. Comput. Commun. Control. IC4 2015*, 2015.

[23] P. L. Borde and R. R. Manza, “Analysis Of Orthogonal Moments For Recognition Of Handwritten MODI Numerals,” *J. Sci. Technol.*, vol. 4, no. 1, pp. 36–43, 2015.

[24] J. Tripathy, “Reconstruction of Oriya Alphabets Using Zernike Moments,” *Int. J. Comput. Appl.*, vol. 8, no. 8, pp. 26–32, 2010.

[25] K. V Kale, P. D. D. (Patil), S. V Chavan, M. M. Kazi, and Y. S. Rode, “Zernike Moment Feature Extraction for Handwritten Devanagari Compound Character Recognition,” *Int. J. Adv. Res. Artif. Intell.*, vol. 3, no. 1, pp. 459–466, 2014.

[26] M. Oujaoura, R. El Ayachi, M. Fakir, B. Bouikhalene, and B. Minaoui, “Zernike moments and neural networks for recognition of isolated Arabic characters,” *Int. J. Comput. Eng. Sci.*, vol. 2, no. 3, pp. 17–25, 2012.

[27] S. L. Chandure and V. Inamdar, “Performance analysis of handwritten Devnagari and MODI Character Recognition system,” *Int. Conf. Comput. Anal. Secur. Trends, CAST 2016*, pp. 513–516, 2017.

[28] U. Bhattacharya, M. Shridhar, and S. K. Parui, “On Recognition of Handwritten Bangla Characters,” in *Proceedings of the 5th Indian Conference on Computer Vision, Graphics and Image Processing*, 2006, pp. 817–828.

[29] A. S. Ramteke and G. S. Katkar, “Recognition of Off-line Modi Script : A Structure Similarity Approach,” *Proceedings- Int. J. ICT Manag.*, vol. 1, no. 1, pp. 12–15, 2013.

[30] F. Alavipour and A. Broumandnia, “Farsi Character Recognition Using New Hybrid Feature Extraction Methods,” *Int. J. Comput. Sci. Eng. Inf. Technol.*, vol. 4, no. 1, pp. 15–25, 2014.

[31] P. A. Patil, “Character Recognition System for Modi Script,” *Int. J. Comput. Eng. Res.*, pp. 31–38, 2016.

[32] P. Sharma, “Classification in Pattern Recognition : A Review,” *Int. J. Comput. Eng. Res.*, vol. 3, no. 4, pp. 298–306, 2013.

[33] C. Liu and H. Fujisawa, “Classification and Learning Methods for Character Recognition : Advances and Remaining Problems,” *Stud. Comput. Intell. Springer Berlin,heidelb.*, pp. 1–23, 2008.

[34] S. Anam, “An Approach for Recognizing Modi Lipi using Otsu’s Binarization Algorithm and Kohenen Neural Network,” *Int. J. Comput. Appl.*, vol. 111, no. 2, pp. 28–34, 2015.

[35] D. N. Besekar, “Special Approach for Recognition of Handwritten MODI Script ’ s Vowels,” *Int. J. Comput. Appliations*, pp. 48–52, 2012.

[36] D. N. Besekar, “Study for Theoretical Analysis of Handwritten MODI Script – A Recognition Perspective,” *Int. J. Comput. Appl.*, vol. 64r, no. 3, pp. 45–49, 2013.

[37] S. Rathi, “Recognition and Conversion of Handwritten MODI Characters,” *Int. J. Tech. Res. Appl.*, vol. 111, no. 2, pp. 28–34, 2015.

[38] B. P. Chacko, V. V Krishnan, G. Raju, and B. P. Anto, “Handwritten character recognition using wavelet energy and extreme learning machine,” *Int. J. Mach. Learn. Cybern.*, vol. 3, no. 2, pp. 149–161, 2012.

[39] S. S. Shelke and S. S. Apte, “A Multistage Handwritten Marathi Compound Character Recognition Scheme using Neural Networks and Wavelet Features,” *... Pattern Recognit.*, vol. 4, no. 1, pp. 81–94, 2011.

[40] G. Hinton, “Learning multiple layers of representation,” *Trends Cogn. Sci.*, vol. 11, no. 10, 2007.

[41] G. Hinton *et al.*, “Deep Neural Networks for Acoustic Modeling in Speech Recognition,” *IEEE Signal Process. Mag.*, vol. 29, pp. 82–97, 2012.

[42] L. Deng, “Deep Learning:Methods and Applications,” *Found. Trends Signal Process.*, vol. 7, no. 3–4, pp. 197–387, 2014.

[43] Y. Bengio, A. Courville, and P. Vincent, “Representation Learning: A Review and New Perspectives,” *IEEE Trans. Pattern Aalysys Mach. Intell.*, vol. 35, no. 1993, pp. 1–34, 2013.

[44] G. . Hinton and R. . Salakhutdinov, “Reducing Dimensionality of Data with Neural Network,” *Science (80-.).*, vol. 313, no. 5786, pp. 504–507, 2006.

[45] M. Sepahvand, F. Abdali-mohammadi, and F. Mardukhi, “Evolutionary Metric-Learning-Based Recognition Algorithm for Online Isolated Persian / Arabic Characters , Reconstructed Using Inertial Pen Signals,” *IEE Trans. Cybern.*, vol. 47, no. 9, pp. 2872–2884, 2017.

[46] M. K. Jindal, R. K. Sharma, and G. S. Lehal, “Segmentation of touching characters in upper zone in printed Gurmukhi script,” *Proc. 2nd Bangalore Annu. Comput. Conf. 2nd Bangalore Annu. Comput. Conf. - Comput. ’09*, p. 1, 2009.

[47] D. C. Cires, U. Meier, and L. M. Gambardella, “Convolutional Neural Network

Committees For Handwritten Character Classification," *Int. Conf. Doc. Anal. Recognit.*, vol. 10, pp. 1135–1139, 2011.

[48] D. Sen Maitra, U. Bhattacharya, and S. K. Parui, "CNN based common approach to handwritten character recognition of multiple scripts," *Proc. Int. Conf. Doc. Anal. Recognition, ICDAR*, vol. 2015-Novem, pp. 1021–1025, 2015.

[49] X. Y. Zhang, F. Yin, Y. M. Zhang, C. L. Liu, and Y. Bengio, "Drawing and Recognizing Chinese Characters with Recurrent Neural Network," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 40, no. 4, pp. 849–862, 2018.

[50] Y. Chherawala, P. P. Roy, and M. Cheriet, "Feature Set Evaluation for Offline Handwriting Recognition Systems : Application to the Recurrent Neural Network Model," *IEE Trans. Cybern.*, vol. 46, no. 12, pp. 2825–2836, 2016.

[51] I.-J. Kim and X. Xie, "Handwritten Hangul recognition using deep convolutional neural networks," *Int. J. Doc. Anal. Recognit.*, vol. 18, no. 1, pp. 1–13, 2015.

[52] Y. Bengio, "Learning Deep Architectures for AI," *Found. Trends® Mach. Learn.*, vol. 2, no. 1, pp. 1–127, 2009.

[53] M. Maggipinto, C. Masiero, A. Beghi, and G. A. Susto, "A Convolutional Autoencoder Approach for Feature Extraction in Virtual Metrology," *Procedia Manuf.*, vol. 17, pp. 126–133, 2018.

[54] A. Gogna and A. Majumdar, "Discriminative Autoencoder for Feature Extraction: Application to Character Recognition," *Neural Process. Lett.*, vol. 49, no. 3, pp. 1723–1735, 2019.

[55] T. Solley, "A Study of Representation Learning for Handwritten Numeral Recognition of Multilingual Data Set," *Springer, Lect. Notes Networks Syst.*, vol. 10, pp. 475–482, 2018.

[56] S. Kulkarni, P. Borde, R. Manza, and P. Yannawar, "Text Line Segmentation of Handwritten Historical MODI Documents," in *International Conference on Information, Communication and Computing Technology (ICICCT2017)*, 2017, pp. 1–12.

[57] Y.-K. Chen and J.-F. Wang, "Segmentation of single- or multiple-touching handwritten numeral string using background and foreground analysis," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 22, no. 11, pp. 1304–1317, 2000.

[58] U. Garain and B. B. Chaudhur, "Segmentation of touching characters in printed Devnagari and Bangla scripts using fuzzy multifactorial analysis," *Proc. Sixth Int. Conf. Doc. Anal. Recognit.*, pp. 805–809, 2001.

[59] V. P. Dhaka and M. K. Sharma, "An efficient segmentation technique for Devanagari offline handwritten scripts using the Feedforward Neural Network," *Neural Comput. Appl.*, vol. 26, no. 8, pp. 1881–1893, 2015.

[60] A. Rehman and T. Saba, "Performance Analysis of Character Segmentation Approach for cursive Script on Benchmark Database," *Digit. Signal Process.*, vol. 21, no. 3, pp. 486–490, 2011.

[61] P. Sivakumar, G. Arts, and G. Arts, “A review on image segmentation techniques,” *Int. J. Adv. Res. Comput. Eng. Technol.*, vol. 5, no. 3, 2016.

[62] G. Seerha, “Review on Recent Image Segmentation Techniques,” *Int. J. Comput. Sci. Eng.*, vol. 5, no. 02, pp. 109–112, 2013.

[63] A. Ramteke and M. Rane, “A Survey on Offline Recognition of Handwritten Devanagari Script,” *Int. J. Sci. Eng. Res.*, vol. 3, no. 5, pp. 782–796, 2012.

[64] S. A. M. O. Chacko, A. Joseph, J. J. Anchanattu, S. Sreelakshmi, and V. A. Kumar, “Offline Handwritten Character Recognition in South Indian Scripts : A Broad Visualization,” *Int. J. Comput. Sci. Inf. Technol.*, vol. 6, no. 3, pp. 2314–2317, 2015.

[65] U. Pal, R. Jayadevan, and N. Sharma, “Handwriting Recognition in Indian Regional Scripts : A Survey of Offline Techniques,” *ACM Trans. Asian Lang. Inf. Process.*, vol. 11, no. 1, 2012.

[66] O. Samanta, R. Anandarup, U. Bhattacharya, and S. K. Parui, “Script Independent Online Handwriting Recognition,” in *13th International Conference on Document Analysis and Recognition (ICDAR*, 2015, pp. 1251–1255.

[67] N. Saikia and S. R. Nirmala, “A Review on Recognition of Online Handwriting in Different Scripts,” *IOSR J. VLSI Signal Process.*, vol. 8, no. 2, pp. 19–29, 2018.

[68] P. Natarajan, S. Saleem, R. Prasad, and K. MacRostie, Ehry Subramanian, “Multi-lingual Offline Handwriting Recognition Using Hidden Markov Models: A Script-independent Approach,” in *Proceedings of the 2006 Conference on Arabic and Chinese Handwriting Recognition*, 2008, pp. 231–250.

[69] I. Goodfellow, Y. Bengio, and A. Courville, *Deep Learning*. 2016.

[70] M. Shopon, N. Mohammed, and M. A. Abedin, “Bangla handwritten digit recognition using autoencoder and deep convolutional neural network,” *IWCI 2016 - 2016 Int. Work. Comput. Intell.*, no. December, pp. 64–68, 2017.

[71] A. Achuthan, M. Rajeswari, D. Ramachandram, M. E. Aziz, and I. L. Shuaib, “Wavelet energy-guided level set-based active contour: A segmentation method to segment highly similar regions,” *Comput. Biol. Med.*, vol. 40, no. 7, pp. 608–620, 2010.

[72] R. Jana and S. Bhattacharya, *Character Recognition from Handwritten Image Using Convolutional Neural Networks*, no. March. Springer Singapore, 2019.

[73] P. Keserwani, T. Ali, and P. P. Roy, “Handwritten Bangla character and numeral recognition using convolutional neural network for low-memory GPU,” *Int. J. Mach. Learn. Cybern.*, vol. 10, no. 12, pp. 3485–3497, 2019.

[74] Antonio Carlos Gay Thomé, “SVM Classifiers – Concepts and Applications to Character Recognition,” in *IntechOpen*, 2012, pp. 25–30.

[75] M. R. Phangtriastu, J. Harefa, and Dian Felita Tanoto, “Comparison Between Neural Network And Support Vector Machine in Optical Character Recognition.” .

LIST OF PUBLICATIONS

Sr No.	Category	Publisher/Conference Details	Title of paper	Publication details
1	Journal publication (Scopus Indexed)	PERTANIKA Journal of Science & Technology (Scopus Indexed)	Feature Extraction and Classification Techniques of MODI Script Character Recognition	e-ISSN 2231-8526 Volume 27 (4) Oct. 2019
	Scopus Link : https://www.scopus.com/sourceid/19600162021 Available on : http://www.pertanika.upm.edu.my/Pertanika%20PAPERS/JST%20Vol.%2027%20(4)%20Oct.%202019/12%20JST-1336-2018.pdf			
2	Journal publication	IEEE Xplore (Scopus indexed)	Handwritten Character Recognition of MODI Script using Convolutional Neural Network based feature extraction and SVM classifier	doi:10.1109/ICSIP49896.2020.9339435
	Link: -https://ieeexplore.ieee.org/document/9339435			
3	Book Chapter	Springer - Book Title - ICT Analysis and Applications	Character Recognition of MODI Script using Distance Classifier Algorithms	eISBN :978-981-15-0630-7 Series Volume -93
	Available on :-https://link.springer.com/chapter/10.1007/978-981-15-0630-7_11			
4	Scopus indexed Paper	Springer Lect. Notes in Networks, Syst.	OCR System Framework for MODI Scripts using Data Augmentation and Convolutional Neural Network	DOI - https://doi.org/10.1007/978-981-15-5309-7_21
	Available on :- https://link.springer.com/chapter/10.1007/978-981-15-5309-7_21			
5	Conference Paper (Scopus Indexed)	International Conference on Data Science for Computational Security	Efficient Handwritten Character Recognition of MODI Script using Wavelet Transform and SVD	Springer Lect. Notes in Networks, Syst . DOI - https://doi.org/10.1007/978-981-15-5309-7_24
	Available on :- https://link.springer.com/chapter/10.1007/978-981-15-5309-7_24			
6	Conference Paper (Scopus Indexed)	International Conference on ICT for Intelligent systems	Data Augmentation for Handwritten Character Recognition of MODI Script using Deep Learning Method	SPRINGER -Smart Innovation, Systems and Technologies, Vol. 196, (Chapter 51)

	Available on - https://link.springer.com/chapter/10.1007/978-981-15-7062-9_51			
7	Accepted for Springer publication	Fifth International Conference on Information and Communication Technology for Competitive Strategies (ICTCS 2020)	Offline Handwritten Character Recognition of MODI Script using Wavelet Transform and Decision Tree Classifier	To be published in conference proceedings by Springer LNNS. Series)

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Review article

Feature Extraction and Classification Techniques of MODI Script Character Recognition

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ABSTRACT

Machine simulation of human reading has caught the attention of computer science researchers since the introduction of digital computers. Character recognition is the process of recognizing either printed or handwritten text from document images and converting it into machine-readable form. Character recognition is successfully implemented for various foreign language scripts like English, Chinese and Latin. In the case of Indian language scripts, the character recognition process is comparatively difficult due to the complex

Character Recognition of MODI Script Using Distance Classifier Algorithms

Solley Joseph, Jossy P. George and Suhas Gaikwad

Abstract Machine simulation of human reading is an active research area since the introduction of digital computers. Optical character recognition aims at the recognition of printed or handwritten text from document images and converting the same into a machine-readable form. The focus of this work is handwritten character recognition of MODI Script. A proper recognition system for handwritten documents enables it to be conveniently viewed, edited, and shared via electronic means. The development of a character recognition system for some of the ancient script is still a challenging task due to the complex nature of the script. MODI script is one such script which is the shorthand form of the Devanagari script in which Marathi was written. Though at present MODI script is not an official script, there exists a

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We wish the authors all the very best for future endeavors.
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1	Applied Machine Learning Using Python	Feb 2018
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Faculty Development Programmes

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1	Introduction to Artificial Intelligence and Machine Learning	Geetanjali College of Engineering Hyderabad, in association with CSI-Hyderabad	20 - 26th May 2020
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